I. C. 6501 August, 1931

DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

INFORMATION CIRCULAR

ESSENTIAL FACTORS INFLUENCING SUBSIDENCE AND GROUND MOVEMENT

RECEIVED
SEP 24 1931
O. S. U. LIBRARY

BY

W. R. CRANE

I.C.6501,
August, 1931.

INFORMATION CIRCULAR

DEPARTMENT OF COMMERCE - BUREAU OF MINES

ESSENTIAL FACTORS INFLUENCING SUBSIDENCE AND GROUND MOVEMENT[1]

By W. R. Crane[2]

INTRODUCTION

Subsidence and ground movement are phenomena common to and attendant upon practically all large-scale mining operations, and under certain conditions may occur in all workings, large and small.

The interpretation of the cause of failure in rock masses involves a study of the nature of planes of weakness common to all rocks. The dominating planes of weakness can readily be determined by observation in any given locality, and in order of importance in the study of subsidence are (1) faulting planes, (2) bedding planes, (3) joint planes, and (4) other prominent planes of weakness such as thrust and shear planes and contacts. This report has mainly to do with the third item, joint planes, and is a preliminary statement which is to be followed by a more complete report in bulletin form.

GENERAL CONSIDERATIONS

Planes of weakness make it possible for masses of rock to move more or less readily one upon the other and control the direction of movement. The purpose of this paper is to show the controlling factors under normal conditions. Abnormal conditions necessarily modify normal movements and present special problems.

In the absence of folding, faulting, and igneous intrusions, such as sills and dikes, the regular joint planes determine the extent and direction of ground movement. In the following pages conditions affecting the mechanics of ground movement are explained.

This report is based wholly upon facts obtained by observation on actual failure and movement of rock masses in mines and opencuts, involving 150,000 instrument readings on the strike and dip of joints and slips.

METHOD OF PROCEDURE

The method of procedure in making the observations recorded in this report, together with their classification and interpretation, are discussed in detail.

Observations on the strike, and on the angle and direction of joints and slips were taken on rock exposures either on the surface or underground, or in both places, for distances of one hundred feet or more and at intervals of several hundred feet, the areas tested being well distributed over the property or locality studied.

---

[1] - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6501."

[2] - Senior mining engineer, U. S. Bureau of Mines.

725540

The data collected were classified according to angles of bearing and dip, the number of observations taken on certain groups of angles being determined by their relative prominence. The relative prominence of the angles thus measured forms the basis for determining the angle upon which failure will take place, or the so-called angle of draw.

Of the information secured from the observations, that of the dip of the joint planes is most important; next in importance is the bearing or strike of the joint planes, as the application of the angle of draw to the periphery of the workings depends upon it.

CONTROLLING FACTORS

The determination and recording of systematic planes of weakness that are controlling factors in the failure and movement of rock masses form the basis for determining the direction of movement when failure takes place. Rocks break according to system unless disturbed by irregularities largely due to cross-bedding in stratified formations, schistosity in metamorphic rocks, and flow or thrust planes in igneous rocks. The series of joints in any particular locality must be determined by observations on their strike and dip, which define planes along which the rock fails most readily and in accordance with the prominence of the joints determine the planes of movement of rock masses and the angles of draw.

The terms "joint" and "slip" are commonly used by miners in referring to the same phenomena, but they are not identical in definition. A joint is a plane or slightly curved crack which is one of an approximately parallel set ranging from a few inches to many feet apart. Slips are cracks along which movement of the rock has taken place. For the purpose of this report the term "joint" will be used to cover both joints and minor slips in which little movement has taken place.

Joints and slips occur in all rock formations and are arranged in series made up of pairs, at right angles or nearly so. They may be quite rough, particularly in certain rocks such as coarse-grained sandstones, and, depending somewhat upon the direction taken across the formation, one of the planes of a set may be smooth and the other rough.

Shearing is that deformation of rocks brought about by accumulative small lateral movements along innumerable parallel planes, generally resulting from pressure due to folding, faulting, and igneous intrusions, all of which produce schistosity, cleavage, and other metamorphic structures. Shear zones are those in which shearing has occurred on a large scale so that the rock is crushed and brecciated.

Fissures are extensive cracks, breaks, or fractures in rock masses. They differ from joints and slips in width, the latter being generally closed and very regular. Fissures are usually prominent planes of weakness and must be given due consideration in a study of ground movement.

Other planes of weakness that are important factors in subsidence and ground movement are bedding, faults, contacts between formations including dikes and sills, and unconsolidated formations. Rock masses may be extensively broken by earth movement, the rock being shattered into small pieces with no semblance of order or system. Such shattered areas may be considered as unconsolidated formations so far as ground movement and subsidence are concerned.

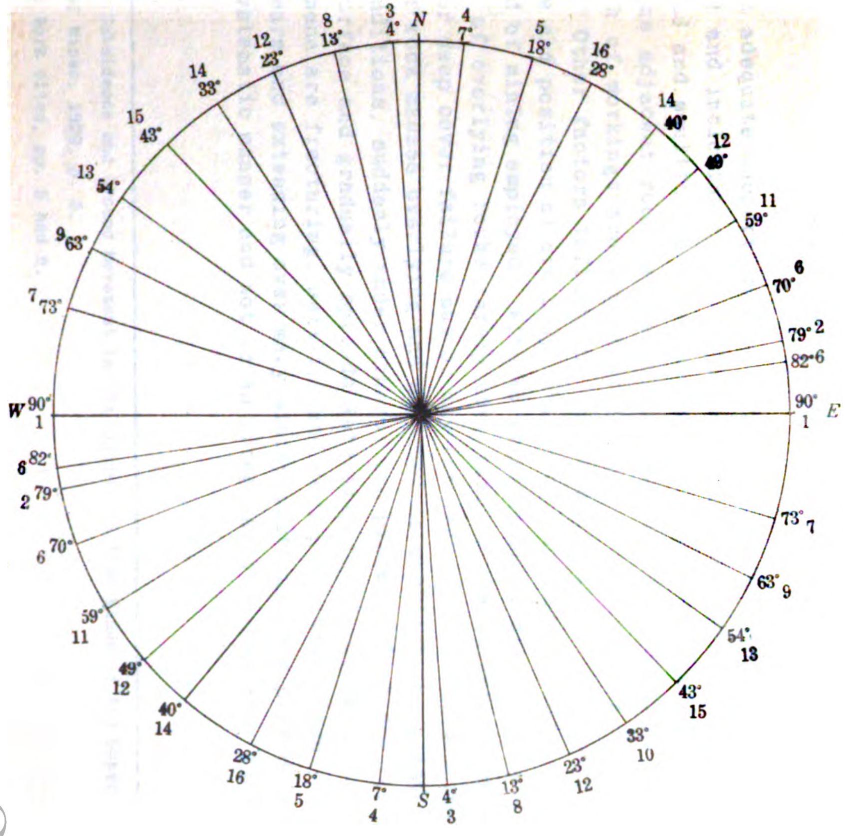


Figure 1.—Relative prominence and bearings of joints in a typical case

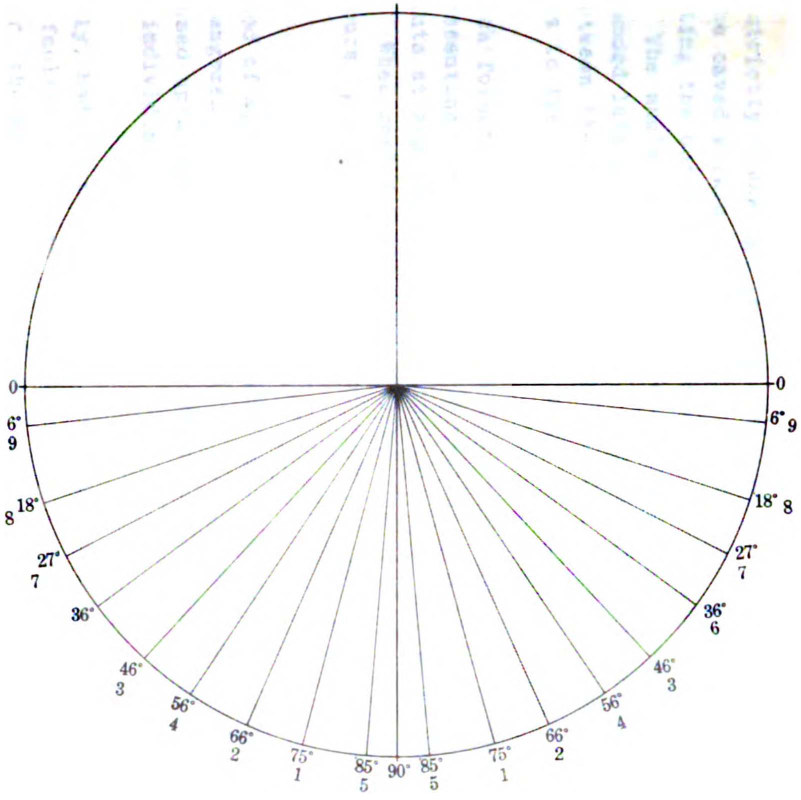


Figure 2.—Relative prominence and vertical distribution of angles of dip of joints in a case typical for both igneous and metamorphic rocks

Draw, strictly speaking, is the distance on the surface to which the subsidence extends beyond the caved workings. The angle of draw is the angle formed with the horizontal by a line connecting the outer edge of the draw on the surface with the nearest point of the caved workings. The angle of draw may not be permanent but may decrease with time or as workings are extended laterally or in depth. When the force of gravity exceeds the frictional resistance between the portions of rock affected, movement occurs on a plane extending from the workings to the surface along the angle of draw.

All rock formations regardless of kind or condition are cut by series of joints, each series representing a movement of the formation. The simplest condition is represented by a pair of joints at approximately right angles; the more complex may have a score or more pairs of joints. When rock formations are broken due to the removal of underground support, the movement occurs upon existing planes of weakness and not upon fresh breaks across the formations.

A method of systematically recording the essential data concerning joints is indicated by the arrangement of bearings and angles of dip as shown in Figure 1 and 2. Relative prominence is based upon the number of joints and slips observed and to a less extent upon the size of the individual faces exposed.

Normally, bedding planes are the most important factors in failure and movement of rocks; next are faults and contacts, while jointing, shearing and schistosity are less important. However, the more general occurrence of joints places them in a position of great importance as the controlling factor in subsidence and ground movement when bedding planes and faults are absent.[3]

CAUSE AND NATURE OF MINE SUBSIDENCE

With adequate support in mine workings no subsidence or movement will occur in the superincumbent and inclosing rocks. When movement takes place it continues until the openings are closed and equilibrium is established. The direct and visible result of the readjustment of the adjacent rock is fracturing, which may eventually reach the surface. The size and depth of workings are important factors in determining the extent of the surface disturbances. Other factors influencing the mode of failure in subsidence and ground movement are shape and position of ore body, character and condition of ore and associated rocks, and the method of mining employed. With workings in small ore bodies and particularly narrow ones, failure of overlying rocks rarely ever reaches the surface except where the cover is shallow. Under deep cover failure may or may not take place. Where conditions are favorable for failure of rock masses overlying and adjacent to workings, breaking occurs progressively under some conditions, suddenly under others, and proceeds from the top of the workings upward to the surface and gradually spreads laterally to the ultimate angle of draw. The resulting phenomena are fracturing, settling and caving of the surface. Observations covering a period of years and extending over many mining sections have proved that rocks break in an orderly and systematic manner and not in an irregular or haphazard fashion, as is commonly supposed.[4]

---

3 - Crane, W. R., Subsidence and Ground Movement in the Copper and Iron Mines of the Upper Peninsula Michigan: Bull. 295, Bureau of Mines, 1929, p. 5.

4 - Crane, W. R., Work cited, pp. 5 and 6.

Bedding Planes

Bedding planes are the planes or surfaces separating the individual beds of a sedimentary rock. They are natural planes of weakness in rock masses, regardless of whether they are bonded or not; furthermore, the irregularity of their distribution or of the spacing between the respective layers or strata of a formation contributes to irregularity in subsidence and ground movement.

Bedding planes may be smooth or they may be very rough, irregular, and undulating. Even with slight tilting or folding they are weakened or opened, thus permitting water to enter and still further weaken them through disintegration of the rock. Irregularities of formation, such as rolls and cross-bedding and particularly the latter, are disturbing factors in ground movement.

Flow surfaces in igneous rocks are often very pronounced and resemble bedding planes; however, they are usually rough and markedly irregular in strike and dip. At angles under 30° they can not be considered of importance as controlling factors in ground movement. It is only when bedding planes are inclined toward workings that they facilitate the movement of rock masses. When dipping away from workings the effect of bedding planes is practically negative. Therefore, it is only in exceptional cases that bedding need be given serious consideration in its effect upon subsidence and ground movement (see fig. 3).

Nature of Joints

Joints are of universal occurrence in rocks and therefore must be considered in connection with ground movement under all conditions. They vary in prominence from a mere plane of weakness to definite breaks often taking the form of open fissures and containing considerable quantities of water. The joints that occur under normal conditions are those to which the author has given particular attention. The larger ones, called "crossings" by the author, are abnormal as to their size and influence on ground movement but are numerous in certain localities and their occurrence must be given special consideration as in the case of faults.

Joints as a rule are not only universal in occurrence, but are extensive, that is, they are very persistent in bearing and dip, and whereas an individual plane may definitely terminate, the plane of weakness continues indefinitely and maintains a definite bearing until deviation is produced by movement and displacement of the formations by folding, by igneous intrusions, or by some action subsequent to the formation of the joints. The study of joints has shown that they differ in character according to their mode of origin. The usual and normal type, and by far the most important, may be designated as regular joints; their origin is not definitely known, but it is evident that a phenomenon of such universal occurrence must be produced by a powerful force. Other joints may be said to have known origins, the terms employed in their designation usually indicating the character of the force responsible for their production - as for instance shear, thrust and flow planes. Curved planes are produced by cooling of igneous rocks, although the more extensive ones may have resulted from stresses producing thrusts. None of the planes of weakness designated as joints are extensive except the regular ones; all others may, therefore, be considered as local phenomena, their beginning and ending often being observable.

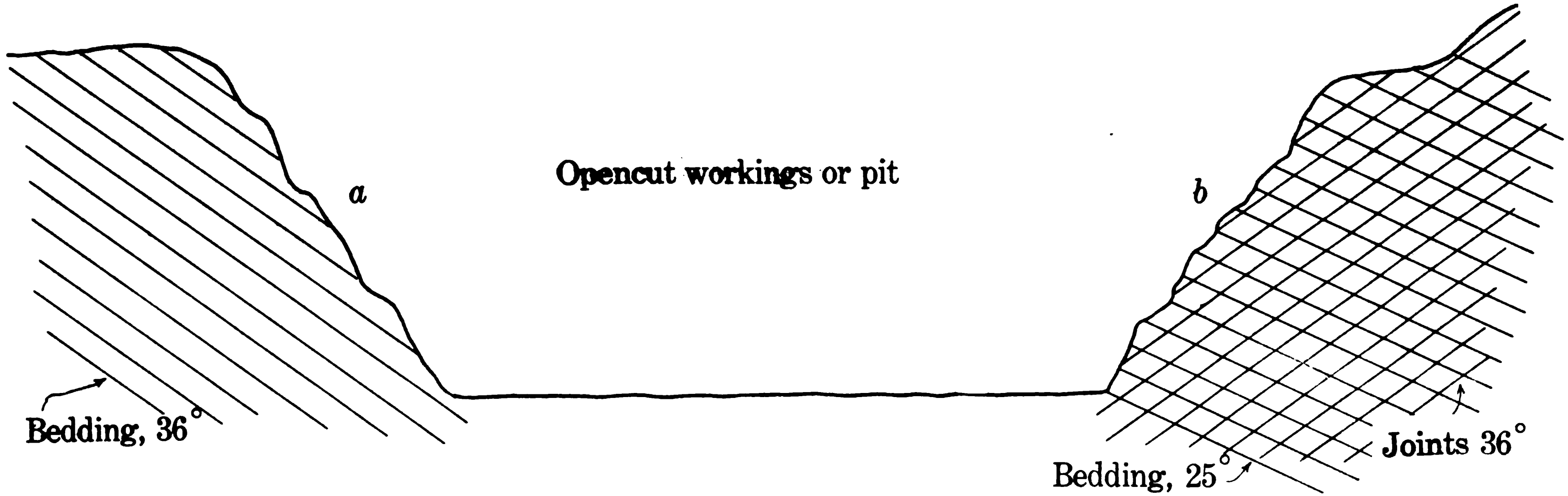


Figure 3.—Vertical section through opencut workings, showing arrangement of bedding and joint planes. Bedding is usually more prominent than joints, and controls ground movement if the beds dip toward the workings; otherwise they have little effect and joints or slips become the controlling factors. On the *a* side of workings bedding controls ground movement, on the *b* side the joints control, therefore the angle of draw is similar on both sides, as the angles of bedding on one side and of joints on the other are the same. This is an actual case, although not drawn to scale

The time element is an important factor not only in the formation of joints but in their prominence. Unconsolidated formations do not usually take on regular jointing until through pressure and cementation they become hard and strong enough to retain a joint. The character of the rock has an important bearing upon the formation of joints and under especially favorable conditions a relatively short period of years may be sufficient to form them. Much remains to be learned regarding the origin of joints, but in a general way it appears from extended observations that fine-grained and thinly stratified formations are most susceptible to their production.

A typical arrangement of joints, the result of a large number of observations at one of the localities studied by the author is shown in Table 1, the prominence being indicated by numbers.

Other and more irregular planes, such as shear, thrust, and flow planes, and dip slips, also occur in rock masses with the regular joints and often complicate an otherwise simple interpretation of the factors affecting ground movement. Moreover, certain arrangements of these irregular planes, may result in their superceding the regular joints in importance as controlling factors in ground movement. Dip slips, which are planes paralleling the dip of the general structural features, occur in all formations alike, igneous and metamorphic as well as sedimentary, and have a much wider application to problems of subsidence than bedding. When they occur in stratified rocks their principal effect is to weaken the bedding planes, permitting movement to take place more readily upon them. In unstratified formations they produce an effect similar in all respects to that produced by bedding. The distribution of strike of joints is shown in Table 1 the most prominent angles being those in column P-1. Curved slips have slight importance as factors contributing to failure and movement in rock formations. They are very local and while prominent are of local application only. Radial joints in folded formations are likewise too irregular and lacking in system to be considered in any study of ground movement.

Occurrence and Nature of Faults

Faults are definite breaks in the continuity of rock formations attended by a movement on one side or the other of the break along the plane of the fault. In this paper we are concerned with four classes of faults; normal or downthrow, thrust or upthrow, rotary or scissor, and curved faults. The normal and thrust faults are most common, while the rotary and curved forms are comparatively rare. The different forms of faults are shown in Figure 4: in A the direction and dip of joints are not affected by the faults; in B the dip of joints is changed, being reduced by a downthrow; in C both strike and dip of joints are changed, the amount depending upon the degree of rotation. D shows how an intrusive may change the dip of bedding and joint planes.

The effect of faults upon ground movement is the same as that of bedding, large joints or crossings, and in fact of all prominent planes of weakness; that is, if the fault plane is inclined toward the workings, movement takes place upon it. On the other hand, if a fault dips away from the workings, movement in the rock occurs not along the fault but across it, following some other plane of weakness. With rotary or scissor faults, planes of movement are rendered discontinuous by the displacement of the bedding or slips which may cross one another. Joints formed after faulting and rotation may present new planes of weakness upon which movement may act but such planes will be nearly vertical.

Table 1.- Distribution of Strike of Joints
(P indicates order of prominence, A is the average angle)

0 - 10°		11 - 20°		21 - 30°		31 - 40°		41 - 50°		51 - 60°		61 - 70°		71 - 80°		81 - 90°	
E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
2	8	18	14	29	24	31	39	50	48	53	60	67	67	77	74	84	87
10	8	20	16	28	29	33	38	47	48	51	53	68	65	73	78	86	83
6	A-8	12	20	28	26	36	38	48	46	53	57	70	65	71	73	82	88
A-6	P-15	11	15	24	21	38	40	49	42	52	52	70	70	73	77	88	83
P-14		15	A-18	30	30	35	36	42	44	54	51	68	63	77	72	87	82
		A-15	P-13	28	27	36	35	47	47	51	55	62	64	77	A-75	84	85
		P-12		28	27	36	34	48	45	58	52	66	A-66	72	P-12	89	82
				25	30	35	40	45	42	54	60	62	P-11	78		82	84
				25	24	37	35	48	50	54	A-55	62		72		82	A-84
				30	23	38	A-37	50	50	54	P-10	66		72		83	P-10
				30	24	34	P-9	43	49	60		63		76		A-85	
				27	21	39		50	A-46	56		63		74		P-8	
				29	A-26	32		45	P-7	52		70		80			
				21	P-6	32		42		57		62		80			
				30		31		47		57		64		80			
				29		37		45		51		68		80			
				30		34		44		52		65		76			
				30		36		42		52		A-66		A-76			
				28		32		46		57		P-5		P-5			
				28		38		50		59							
				23		33		46		51							
				30		40		42		A-54							
				21		40		46		P-4							
				26		34		41									
				30		32		46									
				21		34		45									
				30		35		49									
				28		37		42									
				30		38		49									
				28		32		49									
				30		40		43									
				25		36		A-46									
				A-27		37		P-3									
				P-2		37											
						32											
						32											
						37											
						36											
						32											
						36											
						33											
						35											
						A-35											
						P-1											

Faults may intersect ore bodies and workings within them, and may or may not come to the surface. Without full information relative to the position and extent of faults, it is impossible to foretell the extent of ground movement that may occur.

Contacts Between Formations

The contacts between stratified rocks may be unconformable, whereas contacts between igneous and sedimentary rocks are unconformable except in the case of lava flows and tuffaceous beds which may form a part of a sedimentary series. Owing to the frequency in occurrence of igneous instrusions, particularly in the large metal mines of the west, contacts are numerous and may or may not be important in their influence on ground movement.

Intrusions naturally follow along lines of structural weakness in the invaded rock. When an intrusion of igneous rock follows bedding planes it is called a sill, even if it shifts back and forth between adjacent beds. When a long incursion of igneous rock is made across a bedded formation, it becomes a dike. Dikes cut across beds, and if the contacts are relatively weak they may have a controlling influence on rock movement. The disturbance and weakening of formations by the intrusion of igneous rocks promotes conditions favorable to the breaking down and movement of rock masses.

Schistosity

Schistosity is often developed in metamorphic rocks and is quite variable in character, ranging from an evenness and regularity resembling stratification to a gnarled condition which at points may be angular. There is a marked difference in other characteristics between the gnarled and crumpled areas and the long and smoothly sweeping curves of schistose formations, the former appearing to be stronger and breaking on joints rather than parallel with the schistosity. Failure of a rock mass, however, is facilitated by schistosity, movement taking place quite readily upon it, which with the occurrence of numerous joints cause the rock to fracture and break up readily under ground movement.

Occurrence and Nature of Shatter Zones

Shatter zones are belts in which the rock is cracked in all directions resulting in a network of small fractures. The distribution of shattered areas usually is coextensive with the intrusive areas of igneous rocks; they usually occur along fault planes, and although they occur on both hanging wall and footwall sides they favor the latter. In areas where faults are numerous, shatter zones may occur at more or less regular intervals and may be several hundred feet wide and extend from hundreds to a thousand feet or more vertically.

Such areas of badly broken rock have a profound influence on the failure and movement of rock masses, and as the former and regular planes of weakness have been obliterated, the action accompanying failure of rocks may be very irregular and may afford no definite means of determining either extent of failure or direction of movement. However, as a rule, shattered areas are consolidated to such an extent that incipient planes of weakness or joints are present, thus controlling their failure in a more or less definite way. The breaks as observed by the writer in such formations are vertical or nearly so, thus providing a simple method of determining extent and direction of failure.

Character of Rock

There are two general types of formations that need particular consideration in connection with subsidence and ground movement - namely, consolidated and unconsolidated rocks. The latter are composed of sands, gravel, and cobble stones often associated with clay; the former are solid rocks, stratified, metamorphic and igneous. Any rock of recent or comparatively recent origin that has not become relatively hard and strong by pressure and mineral bonding, thus involving the time element, may be classed as unconsolidated. Such rocks are not dense and firm enough to have become jointed; and breaks in such formations range from the vertical to the angle of repose as limits.[5]

Semiconsolidated formations, on the other hand, have become jointed; and although the joints may not be prominent, they are usually vertical, provided the formation has not been disturbed by earth movement. Typical semiconsolidated formations comprising by far the larger number of this class, are conglomerates formed in river valleys and lake beds. Recent beds of fine sand and silt deposits may also be designated as semiconsolidated if joints are present.

A wide range of rocks with variable characteristics belong to the consolidated class. These rocks are those most commonly encountered in mining and consequently are of particular interest in connection with failure and movement in rock formations. Considering certain characteristics only, the hard, dense rocks are more susceptible to the formation of joints. Softer and tougher varieties of rock often resist systematic fracturing to a marked degree; however, planes of weakness paralleling the joint planes may exist although invisible. As prominence of joints means easy breaking and movement in rock masses, the harder the rock the more readily is ground movement promoted. Thin, hard beds are particularly susceptible to the formation of joints and consequently to failure.

Summary

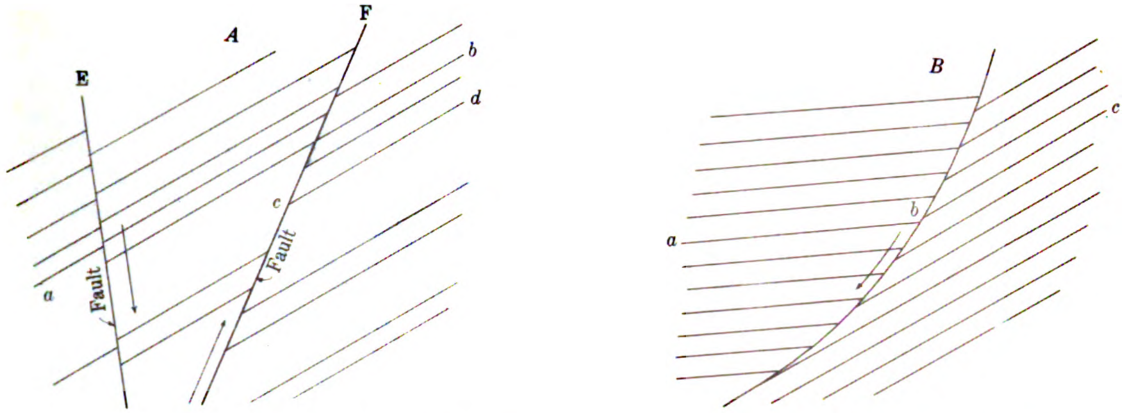
The cause of failure and movement of rock masses is not confined to artificial excavations, as is evident from numerous occurrence of rock slides on rough and precipitous ground. Although any weakening of support is responsible for the setting up of stresses that ultimately cause failure and movement, the main and essential difference between natural and artificial excavation is the time involved in producing these effects, natural agencies being as a rule relatively slow excavators, whereas the systematic efforts of man are locally very rapid.

Excavations are the immediate cause of failure of rocks. The controlling factors are existing planes of weakness; and the results are breaking down or caving within the excavation, settlement or subsidence in superincumbent rocks, and movement in rocks adjacent to the excavation.

The controlling factors are bedding or stratification, faults, contacts between formations, and joints or slips. All of the factors mentioned except joints may be classed as special, while joints are universal in their occurrence and application. The essential characteristics of joints that give them importance as contributing and controlling factors

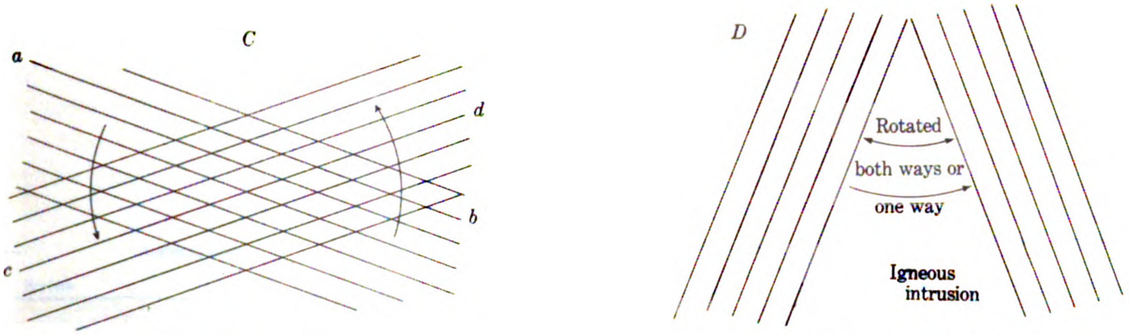
---

5 - W. R. Crane, Subsidence and Ground Movement in the Copper and Iron Mines of the Upper Peninsula Michigan: Bull. 295, Bureau of Mines, 1929, p. 34.



Vertical section through downthrow fault E and thrust F

Vertical section through curved fault



Plan on plane of rotary fault

Change of dip of steeply inclined beds by intrusion of igneous rock

Figure 4.—Sketches showing effect of faults in changing strike and dip of bedding or joint planes

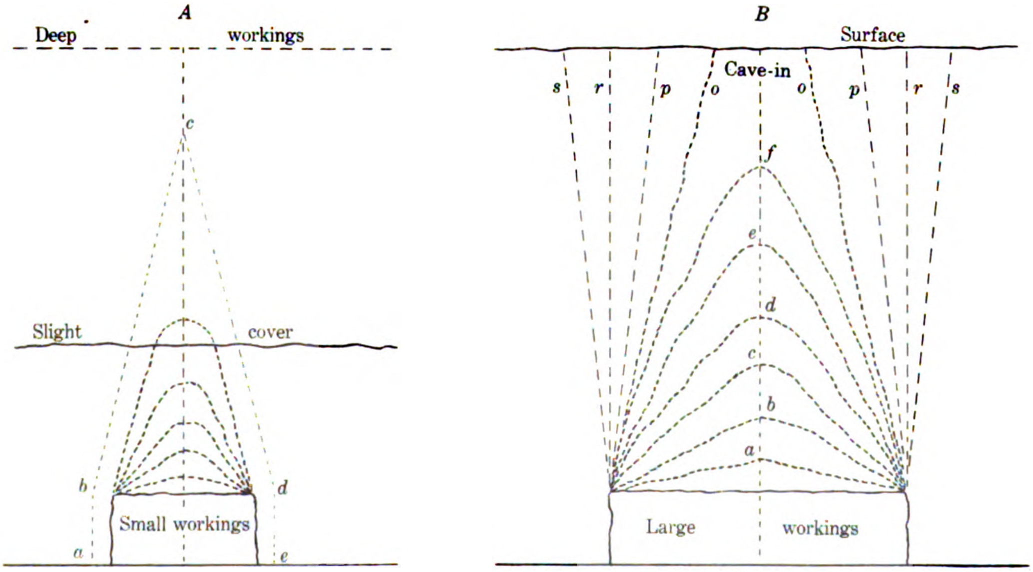


Figure 5.—Vertical section, showing how failure of roof of workings affects overlying rock

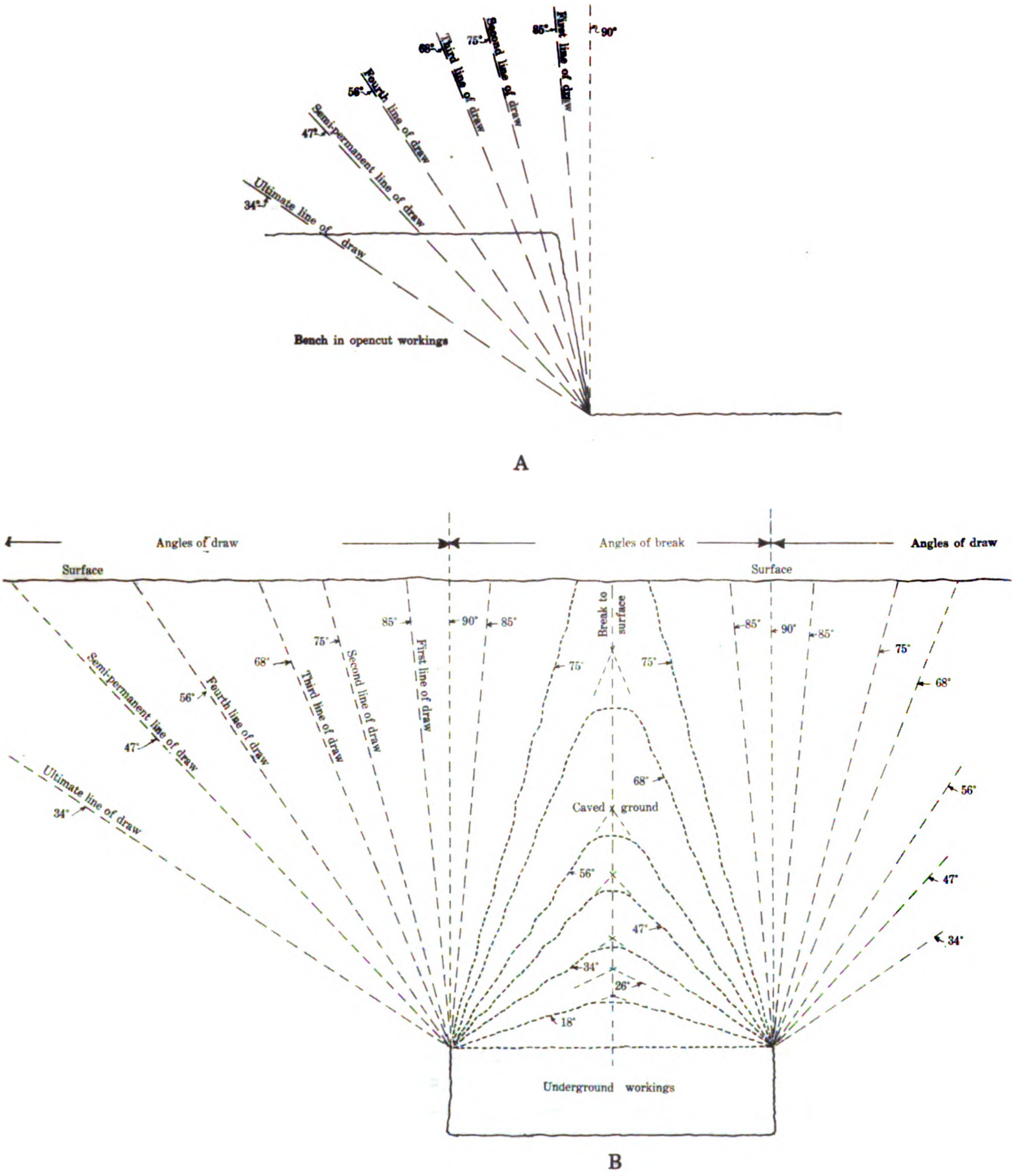


Figure 6.—Progressive decrease in the angle of draw in bench A and underground workings B

in subsidence and ground movement are: large extent both horizontally and vertically, systematic arrangement, and relative smoothness of surface. Other factors such as bedding, faults, contacts, etc., may be much more prominent than joints locally, but aside from bedding are irregular in occurrence. Bedding, while prominent in sedimentary formations, is confined to them and may or may not be more prominent than joints. Furthermore, like all other planes of weakness, bedding must be in the proper position to be an effective agent in ground movement and therefore is of limited application only.

Extended observations under all mining conditions demonstrate beyond question that failure and movement take place upon systematically arranged planes of weakness or joints in rock masses, which constitute the most important factor in failure of rock overlying underground workings Caving in stopes, natural stoping, breaks to the surface or cave-ins, settlement of surface or subsidence, and ground movement all present indubitable evidence of the effect of joints as an ever present factor in contributing to and controlling failure and movement in rock masses.

MODE OF FAILURE

The breaking down of the roof and walls in underground workings and the walls of opencuts is due to the pressure of the overlying rocks. The extent of failure is determined by the size of workings, particularly their horizontal dimensions, and by the character and physical condition of the rock. The height to which failure will reach depends upon the width of opening or stope, provided the length is considerably greater than the width, and unless the thickness of cover is slight and breaks down, the height will remain constant until the width of the opening is increased by failure of the walls. Natural stoping increases the width of opening and in turn increases the height of failure in proportion to the increase in width of opening. Figure 5A shows small and narrow workings which will not break to the surface unless the cover is slight. In large workings, failure of roof continues upward until the surface is reached, as in Figure 5B, passing successively through a, b, c, d, e, f and o, the last stage, o, breaking through to the surface. From this point on, failure extends laterally through p, r, and s to the ultimate draw. The walls of workings are extended by natural stoping permitting caving to a greater height (See a, b, c, d, e in fig. 5A).

It is evident that there is a definite relation between depth of cover and the width of workings necessary to bring about failure of the surface, but owing to differences in the character and condition of the rock no universally definite ratio exists. Furthermore, the excessive weight of adjacent rock masses, presence of water in the rock and other conditions affecting and influencing failure and movement of rock, may be factors seriously affecting the normal procedure in failure.

A cave-in having resulted from breaking down of the roof of a stope, failure continues upward to the surface more or less rapidly until the walls are vertical. Then breaking down of the walls commences. The action now becomes more a sliding than a falling one and is designated as draw, as gravity pulls or draws the rock into the pit.

There is a progressive extension of draw from the vertical to the ultimate angle of draw. This is illustrated in Figure 6 for both bench and underground workings. In the latter a distinction must be made between failure through breaking of roof and that through breaking and draw in the adjacent rock, which is shown in Figure 6B, although the same lines of weakness control in both instances. The first movement or draw is on the steeper angles and is usually quickly accomplished, gradually slowing up as the angles become flatter until further movement is impossible because of friction. The failure in benches of opencuts is similar to that of underground workings, but less pronounced.

Faults and dikes may intersect ore bodies and the inclosing formations, modifying the effect of jointing.

The essential points relative to failure of rock masses may be summarized as follows: (1) Rock breaks according to a systematic arrangement of planes of weakness, with slight irregularities due to breaking between joints; (2) measure of the strike and dip of the joint system is essential; (3) the strike and dip of the most prominent joint planes indicate the direction of movement, the dip being the most important as it gives the angles of draw; (4) the angles of draw show the ultimate limits of breaking or subsidence.

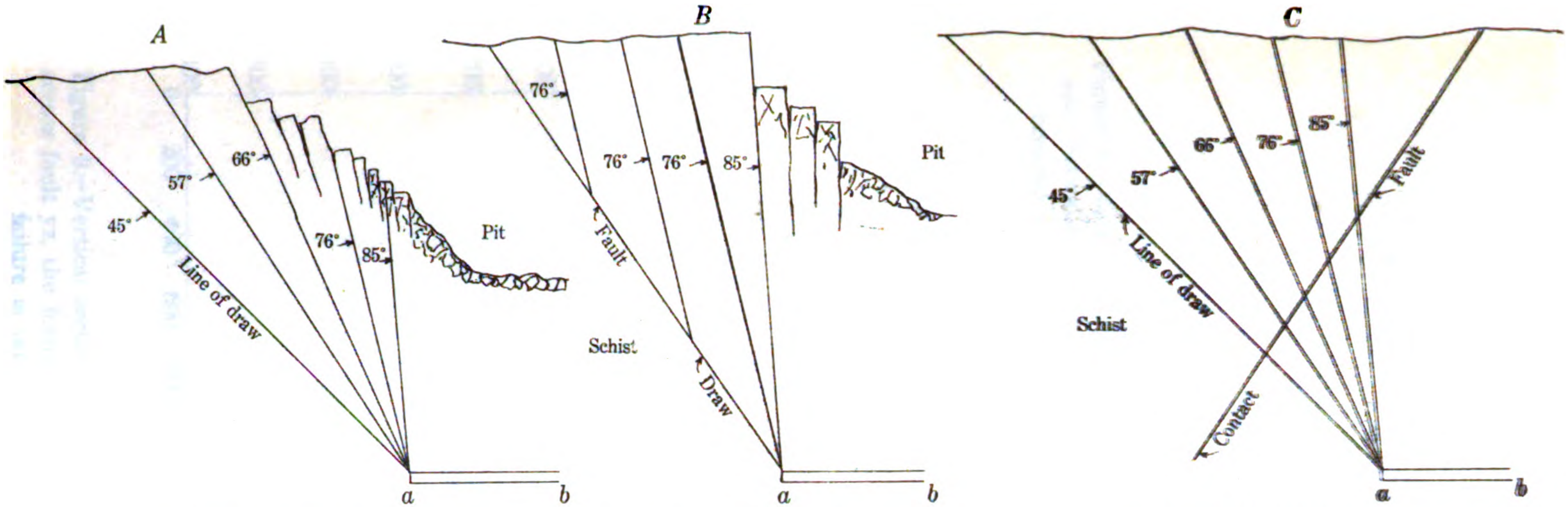
Figures 7, 8, and 9 illustrates various aspects of subsidence and ground movement ranging from movement resulting from normal conditions of draw to the more complicated action resulting from the presence of faults.

DETERMINATION OF STRIKE, DIP, AND DIRECTION OF DIP OF JOINTS

The strike of joints must be known to determine the extent and continuity of the planes of weakness in a given locality or district. The dip of joints, however, has a more important bearing on subsidence and ground movement; the direction of dip is secondary only to the angle of dip, as it gives the direction of movement of rock masses.

Observations on joints should be taken first in a section where they are regular. If a disturbed section is encountered either omit observations therein or make careful selection of joints so that undue importance may not be given to particular joints of the series. For instance, a large number of parallel joints may occur in a sheer zone. Observation taken on all such joints would obviously introduce an error, since their prominence would be exaggerated for the locality as a whole. It is needless to say that care must be exercised in taking observations, as it is upon them that the accuracy of results depends. However, experience in areas of regular jointing readily prepares one for the more difficult task of making proper selection in disturbed localities.

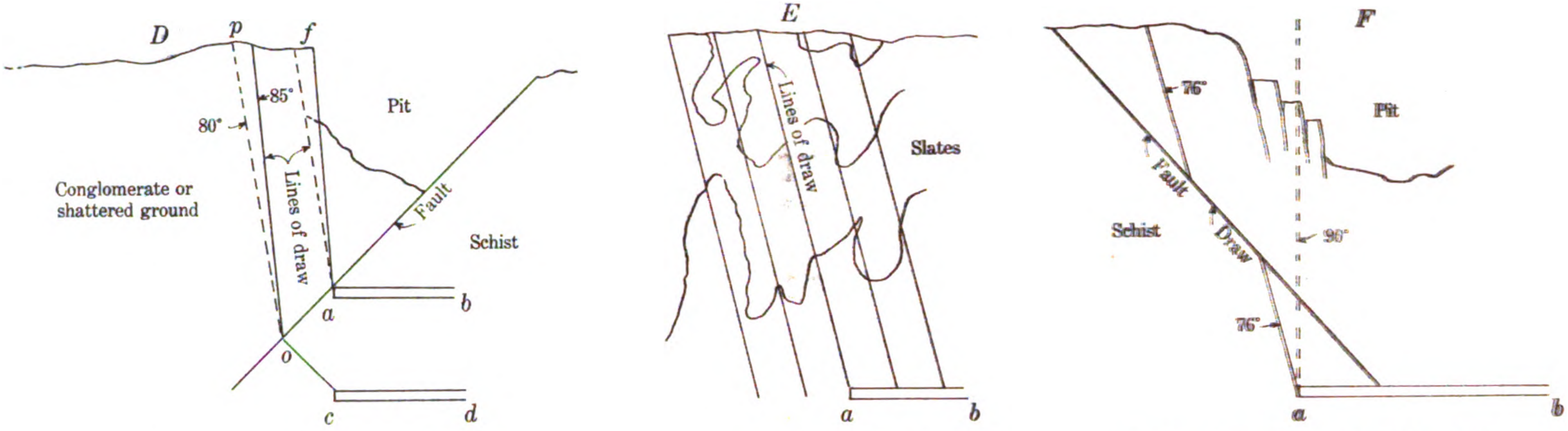
Observations are grouped according to bearing and dip, the groupings indicating the relative prominence of certain joints in the series for a locality. (See Table 1 and fig. 10.) The ideal grouping for a quadrant or 90° would be in 90 columns; then the number of observations in any given column would represent the relative prominence of a certain angle. However, this arrangement is too cumbersome and involves unnecessary refinement. Obviously the error in selecting angles increases with the reduction in number of columns employed in the grouping, and consequently there is a lower limit in the number of columns which should be used. The smallest and at the same time the most convenient number of columns is nine, with ten degrees to the column. While the spread of angles in a column is theoretically ten degrees, yet in reality it is usually limited to about six degrees. In the spread of angles the true angle is just as likely to be below as above the average but the average angle is probably the fairest approximation that can be made.



Planes of weakness in rock adjacent to workings showing normal draw

Effect of fault inclined toward workings

Effect of fault inclined away from workings



Effect of double draw with workings at two levels

Uniform draw in folded formations

Combined draw on fault and slip below fault

Figure 7.–Vertical sections showing effect of faults and joints on rock movement. *A*, Normal condition; *B*, broken ground moving a fault toward the workings; *C*, lack of effect of a fault or contact inclined away from the workings; *D*, effect on draw of two different formations cut by fault with workings at different levels; *E*, joints cutting folded formations in regular and persistent manner; *F*, a double draw on a fault and joint planes

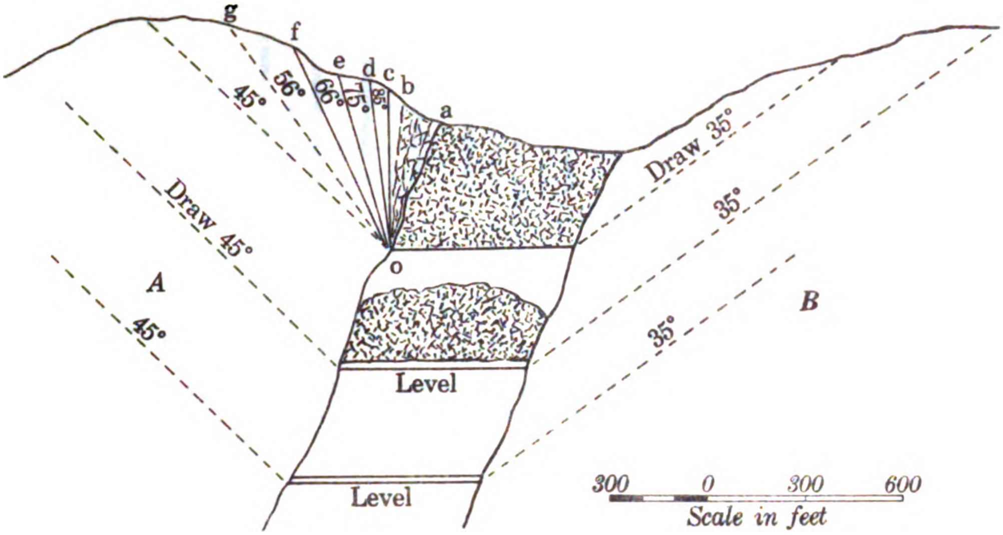


Figure 8.–Vertical transverse section through ore body with different kinds of rock in hanging walls and footwalls at *A* and *B*. The angles of draw are 45° in *A* and 35° in *B*. Pronounced failure has occured at the vertical co, while draw has extended back as far as fo or to an angle of 66°

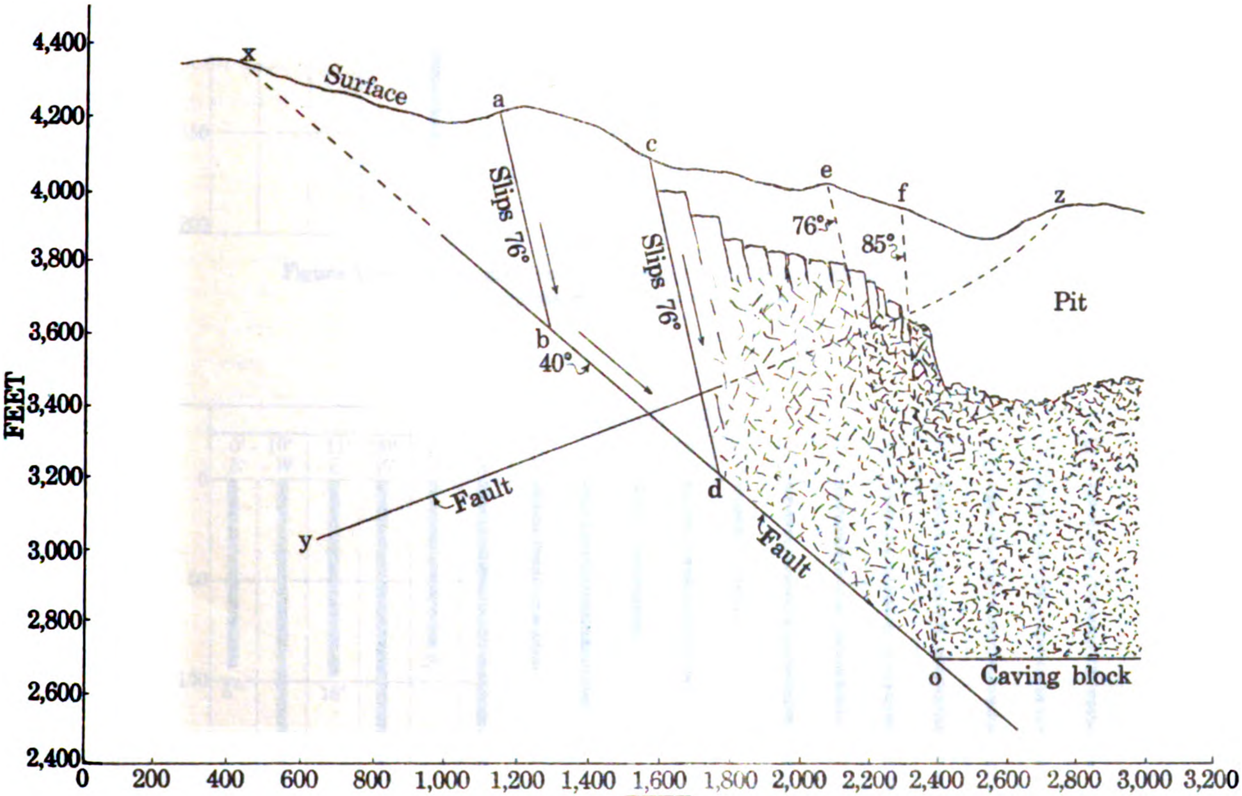


Figure 9.–Vertical section through caving block showing draw taking place on fault xo and cutting across fault yz, the former controlling movement, the latter having no effect upon it. Breaking and failure is taking place on slips above fault plane as shown at ab, cd, and at e and f

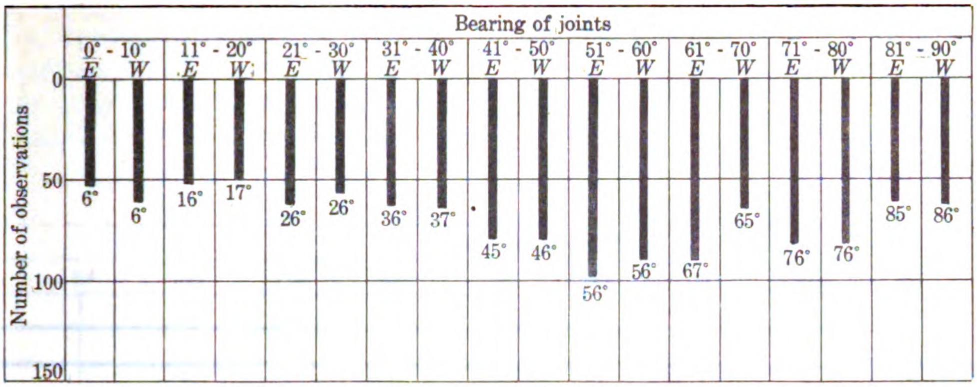


Figure 10.–Distribution and prominence of bearings of joints in a given locality, indicating equal prominence in all directions

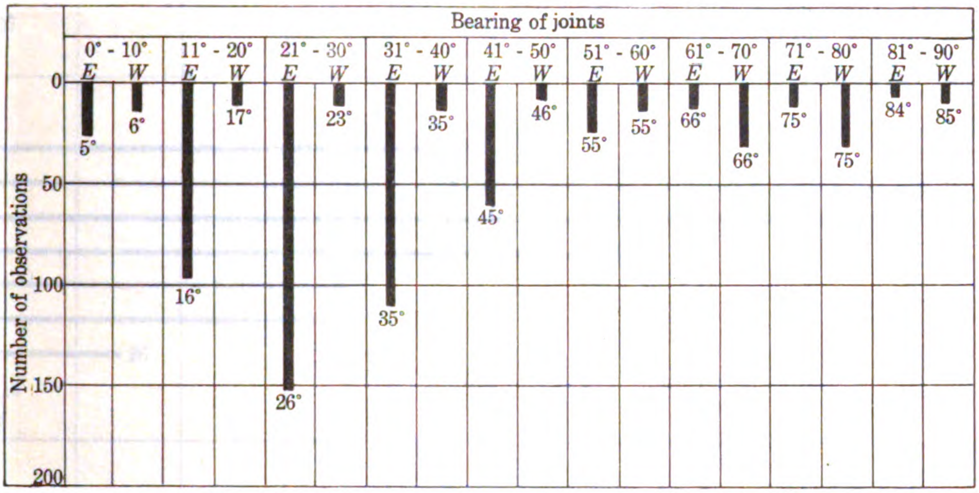


Figure 11.–Unequal distribution of bearings of joints, indicating greater prominence in a few directions

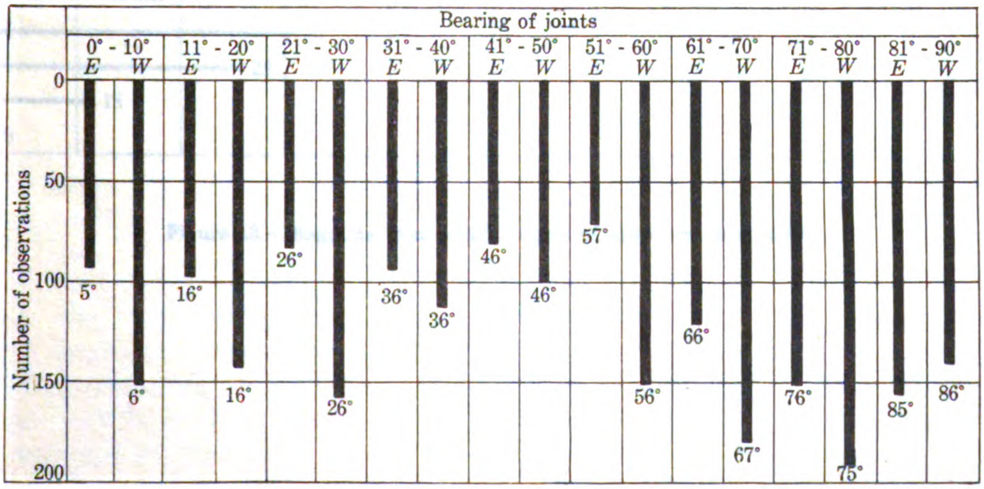


Figure 12.–Combination of Figures 10 and 11

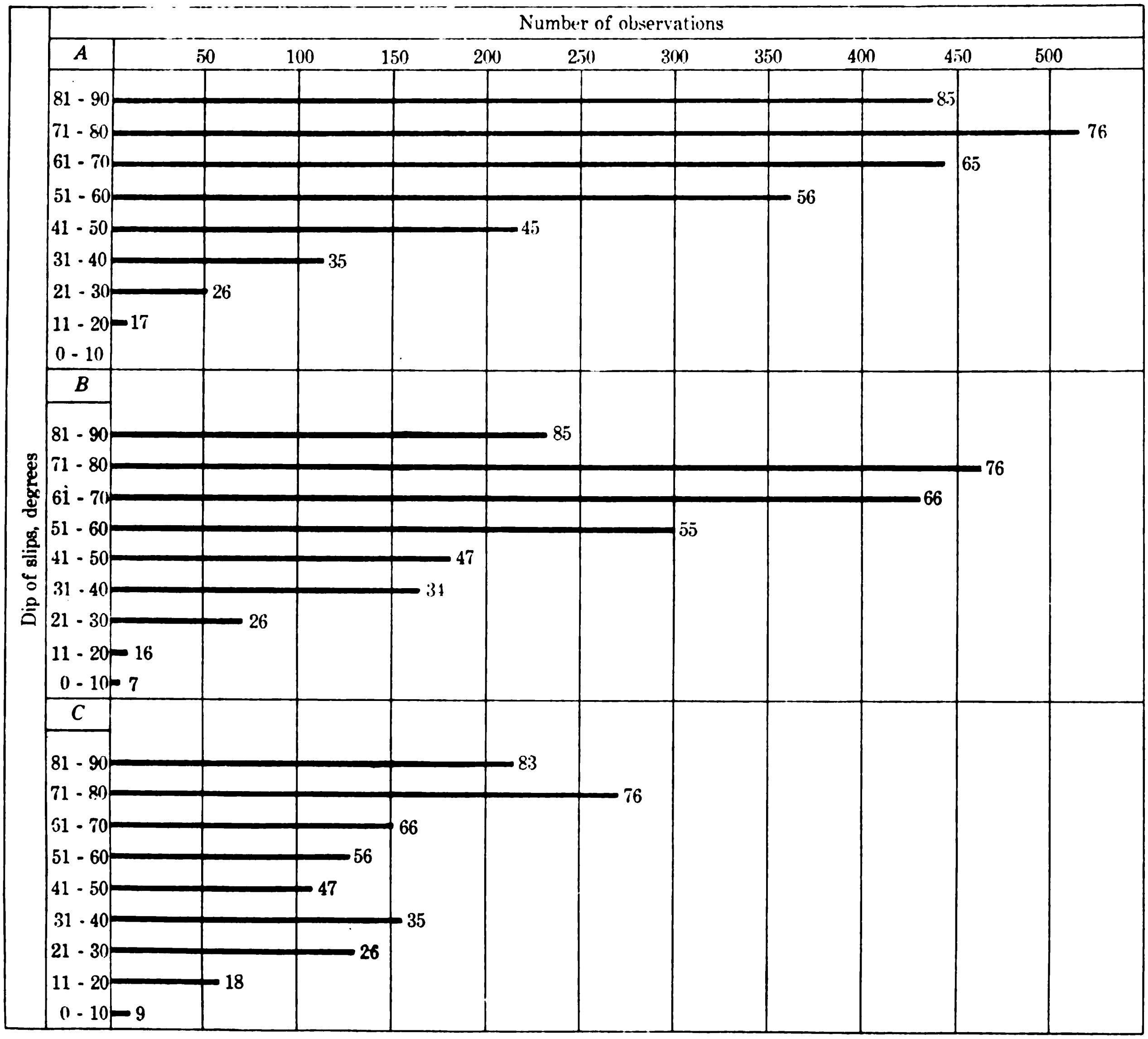


Figure 13.—Diagrams from which angles of draw are determined

The prominence of the bearing of joints in each group is measured by the relative number of readings tabulated in that group. If the prominence is equal in all directions, it may naturally be deduced that jointing is of equal importance in all directions. If, however, certain groups greatly exceed others in prominence, it is concluded that jointing is more effective in those directions.

In the first instance, draw will occur in all directions, whereas in the second instance, it will be more prominent in the direction of the dominating joint planes (see figs. 10, 11 and 12).

Dip of Joints

As the dip of joints is the controlling factor in rock movement, determining the angle of draw, it is quite important that the relation between dip and draw should be thoroughly understood. Observations on dip are taken on the same faces as are those for strike and direction of dip, the data being grouped in columns somewhat similar to the groupings for strike. No attempt is made, however, to introduce the direction of dip, which is considered separately; consequently there is but one column to each group.

Although there is a wide range in types of arrangements of joints according to prominence, yet for the present purpose it is only necessary to mention three as are shown in Figures 13, A, B, and C. In Figure 13B the columns 31 - 40° and 41 - 50° have about equal prominence, whereas in Figure 13C only one column, the 31 - 40°, has an unusual degree of prominence, although the column 21 - 30° is also unusual. The meaning of these variations in prominence is explained under "Interpretation of Results."

Direction of Dip of Joints

The direction of dip of joints is of importance, but need only be considered for those dips that control ground movement; consequently the arrangement of dips according to prominence must be consulted. The most common condition is where the joints have the same angle of dip regardless of direction, a not unusual occurrence with igneous and metamorphic rocks. A similar condition may occasionally be found to exist in bedded deposits that have either been folded or otherwise disturbed by igneous intrusions. With joints dipping at the same angle in all directions the required angle of draw may then be readily applied at any point of the workings, whereas if the direction of movement is more prominent along certain angles of strike, special care must be taken in determining the direction of draw.

The Angle of Draw in Rock Masses

The plane on the angle of draw along which rock masses move or slide is below and back of the broken rock, forming a plane of cleavage between the partly broken and unbroken rock.

The dip of joints determines the angles of draw, but the effective and ultimate draw does not depend entirely upon prominence. The most prominent dips may have high angles, failure by draw taking place upon them after the vertical has been reached by caving. As the angles of draw flatten, the resistance to movement increases until an angle is reached upon which movement of rock masses can not take place (see fig. 6).

The time during which draw may develop lengthens as the angles flatten, unless special and unusual conditions exist that expedite movement. The time element is important therefore, and should be given due consideration in the determination of draw. In determining the ultimate angle of draw, a factor of safety should be taken by selecting an angle somewhat flatter than that determined by observation; higher angles may be chosen if the draw during the life of a mine is alone to be considered.

Interpretation of Data

In the determination of the ultimate angle of draw, the following are controlling factors: (1) prominence of joints, (2) character of joint planes or surfaces, (3) experience in the district, (4) the necessity or desirability of having an adequate factor of safety.

From extended instrument observations in different districts it is obvious that much information has been obtained regarding the physical character of the rock and the condition of the joint planes; in certain localities the planes are clear-cut and smooth, while at other places they are undulating and rough.

In a district where mining has been under way for years with possible subsidence of the surface and the development of draw in the inclosing rocks, considerable information can be obtained relative to the development of draw and its advance from the higher angles to the lowest or ultimate angle of draw. Such information is, however, useful only after all other data has been collected and interpreted; it may reveal unknown and unsuspected weaknesses in the rocks that may take precedence over joints in affecting ground movement.

For safety a slightly smaller angle than the ultimate angle of draw should be chosen, usually from 5 to 10° less according to conditions affecting its choice. Undue caution is not advisable, however, particularly if it means the tying up or loss of considerable ore by employing too low an angle of draw. In some cases the ultimate angle of draw is sufficient safeguard against failure, but with valuable surface property and development openings, an adequate factor of safety should be employed.

The application of data to the determination of actual angles of draw may be shown to best advantage by referring to diagrams embodying actual observations and representing typical occurrences of joints in a variety of rocks. Three cases are cited as representative of conditions in the low-grade copper deposits in porphyry and schists associated with certain barren igneous and metamorphic rocks: (a) joints having dips in regular decreasing order of importance from the high to the low angles, (b) joints having dips with two groups of equal or approximately equal importance, and (c) joints having one group of dips of marked prominence.

The angle of dip of joints is the prime factor in the determination of draw and is, therefore, given special consideration at this point. The strike and direction of dip are merely supplementary to angle of dip and are discussed further on. The application of observation data is discussed in the following cases.

Case A.- Figure 13A shows a normal case - that is one in which the force or forces which produced the joints was regular and well distributed, and further no irregular joints have been formed subsequently. The arrangement shows a systematic decrease from higher to lower dips as represented by the prominence of the respective columns.

Selection from the diagram of the angle of dip that will give the proper angle of draw is more difficult in this arrangement than in most occurrences, as there is a marked regularity in passing from the higher to the lower angles, and it is, therefore, necessary to seek supplementary information. Where mining accompanied by ground movement has been carried on in a locality for many years, ample information is usually available, if properly interpreted. Observations at old abandoned properties and a study of mine maps will reveal the approximate angles at which failure in the rock masses stopped. As a rule, however, such angles are considerably above, that is, higher than the safe angles of draw, due to various irregularities of working and particularly due to the supporting action of waste rock that runs into the workings through cave-ins.

Should the angle obtained from experience in the district indicate an approach to 70°, it is obvious that the angle chosen should not be higher than the average of the next column to the left, namely, 65°. Further, should any group of joints having lower angles be uniformly large, wet, or smoother than the others above and below that group, then it should be chosen, with a factor of 5 or 10° subtracted for additional protection. If the average of such a lower group be 35° then the safe angle of draw would probably be 30°, or if 45°, the draw might well be the average of the next lower group or 35°, thus providing an ample factor of safety.

Assuming that the angle chosen is 35°, that angle can be applied to any direction of working face irrespective of bearing, although the maximum angle of draw will occur where the working face is normal to the direction of dip. The importance of the specially prominent bearings is shown in this connection, and in order to take advantage of them, if any advantage exists, the direction of dip for the 35° column is worked out. If a certain direction of dip predominates then it may be applied to the working faces normal to it, provided there is special reason for additional precautionary measures at such points.

Case B.- A less marked type is where two or more of the groups have prominence considerably greater than the others. The equal or approximately equal prominence of two groups of angles of dip is shown in Figure 13B with the angles 34 and 47° being of approximately equal prominence.

With this arrangement of dips a choice of angle representing the angle of draw can readily be made. Passing the higher angles, 76, 66, and 55°, the angle 47° is reached which would normally be chosen as the angle of draw and an ultimate angle of draw of 40° would be taken as safe. However, as the angle 34° is of nearly equal prominence with that of 47° it is obvious that 34° should be chosen. The application of a factor of safety by reducing the 34° angle by 4° would give ample protection except where the joints in the 34° grouping show excessive weakness through size, character of surface, or wetness.

Case C.- Thrust joints are usually rather low-lying, for instance in the case of "sheeting" in granite. This is well shown in Figure 13C, where the dips of 26 and 35° are of great prominence.

It is obvious that the angle of 35° is the angle that must be chosen, which for safety should be reduced to 30° - the final and ultimate angle of draw. Smoothness or roughness of the joint planes represented in the 35° grouping should be considered, but it is of exceedingly rare occurrence to have rock masses move on an angle lower than 30° - that is, where normal joint planes are involved.

APPLICATION OF DATA ON STRIKE AND DIRECTION OF DIP OF JOINTS

The strikes of joints considered here were taken in igneous and metamorphic rocks and show three types of occurrence: namely (1) those bearing equally in all directions, (2) those bearing principally in a few directions, (3) and those about equally divided between groups one and two (see figs. 10, 11, and 12).

In case (1) as illustrated in Figure 10, the determined angle of draw is applied equally in all directions.

In Case (2), as shown in Figure 11, each prominent group of bearings must receive special consideration. Since movement takes place along the dip of the plane which determines the angle of draw, mine workings parallel with the bearing of the draw plane will have the greatest effect in producing movement.

The combination type which is shown in Figure 12 requires no special discussion. The bearings being prominent in all directions permit the general application of draw to any direction of working face, but should special precautionary measures be desirable, the most prominent bearings should be taken into consideration at points where they are most likely to effect the angle of draw.

The arrangements of the strikes of joints as shown in Figures 10 and 12 and especially that given in the former are particularly favorable to subsidence and ground movement and may be taken advantage of in the application of caving methods in mining.

Summary

Failure of the rock in mine workings is due to insufficient support, and natural support once removed can not be adequately replaced. Failure proceeds upward through the overlying rocks, ultimately breaking through to the surface or more or less seriously affecting it. Under conditions favorable to ground movement, failure extends laterally into the inclosing rock and stops only when resistance to movement exceeds the pressure responsible for failure.

All failure in rocks is contributed to and largely controlled by planes of weakness existing in the rock, the more important being faults, bedding planes, and joints or slips. Which is of the most importance depends upon local conditions of occurrence and prominence. Acting through and in conjunction with these planes of weakness, failure originates in the stopes and breaks to the surface; breaking of rock also extends to the vertical beyond which a sliding action or draw results in further failure until overcome by frictional resistance.

The determination of a definite angle of draw and the direction in which it acts can be readily made by taking observations on the strike, dip, and direction of dip of joints and by analyzing the data obtained.

With definite knowledge of the factors affecting and controlling ground movement the development of properties can be planned for maximum protection of the workings and surface, but the application of such information should not be delayed until failure of the rocks begins.